AN INEXPENSIVE HUMIDIFYING AND COOLING SYSTEM FOR INHALATION CHAMBERS

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A relatively inexpensive method for humidifying and cooling the intake air supply of an animal inhalation chamber is described. Specifically, incorporation of a humidifier into the air intake supply and circulation of cold water around the aerosol intake line is required. Descriptive statistics of 3 sets of relative humidity and temperature data from combustion trials of a military smoke product showed that: (1) mean within-chamber relative humidities were increased approximately 2.5 times over ambient conditions, (2) mean within-chamber temperatures were reduced approximately 10°C, and (3) mean within-chamber relative humidities and temperatures were maintained at 44.4 and 42.5% and at 21.2 and 21.7°C during a series of 1-h combustion tests of the smoke product at 500 and 250 l/min air flow rates, respectively.

INTRODUCTION

Toxicology research, particularly inhalation studies, requires well-controlled environmental-exposure conditions (see Megna, 1984; Raab, 1984). Although the designs for a number of sophisticated inhalation filtering, heating, ventilating, and air conditioning systems have been published (e.g., Hinners et al., 1968; Drew and Laskin, 1973; Megna, 1984; Stavert et al., 1982), many inhalation scientists continue to conduct studies in outdated or retrofitted buildings that afford minimal environmental control of chamber-housing areas.

This report describes several inexpensive additions to the intake air supply of a standard inhalation chamber. The changes afford improved

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control of within-chamber relative humidity (RH) and temperature (T). The humidifying system is recommended to researchers in arid regions where laboratory facilities are not humidified and ambient RH is often less than 30%. The cooling system is recommended for inhalation chamber studies where open-flame combustion is used to generate inhalants and excessive heating of the intake air occurs.

DESCRIPTION OF THE SYSTEMS

Figure 1 is a technical illustration of our inhalation chamber system. The humidifying and cooling modifications were devised by the authors. The other components of the system were developed by scientists at Oak Ridge National Laboratory as an extrusion/combustion generator for inhalation studies involving a red phosphorus-butyl rubber (RP/BR) military smoke (see Holmberg and Moneyhun, 1982).

As shown, humidified air is fed into a Plexiglas chamber and through an Absolute Filter Unit (Young and Bertke, Cincinnati, Ohio). The air then moves to an RH-monitoring chamber (hygro-thermograph; Belfort Instrument Co., Baltimore, Md.) and on to a glass pipe junction. Here, RP/BR is extruded under hydraulic pressure (300–1500 psi) through a 2-mm stainless-steel orifice into the glass pipe junction where it is ignited. Aerosol-laden air then passes through about 7.5 m of flexible and rigid stainless steel pipe to the apex of the inhalation chamber.

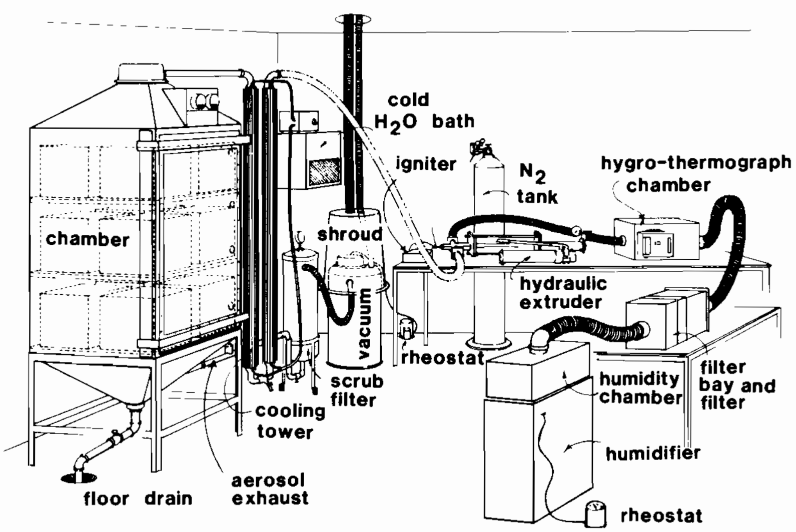

FIGURE 1. Technical illustration of the inhalation chamber system showing the auxiliary air humidification and cooling equipment. (*Note.* Components of the system are scaled relative to the perspective, but the locations of some components have been drawn to improve the pictorial display.)

The 2 rigid segments of pipe act as cooling towers and are surrounded by cold-water jackets through which 1°C water is circulated. The chamber is a standard 1.7-m^3 stainless steel unit with autoclave door (Young and Bertke, Cincinnati, Ohio). The aerosol is exhausted at the base of the chamber.

Humidifying System

Humidification of the intake air supply was accomplished with a commercial console humidifier (Emerson Electric Co., St. Louis, Mo.). A Plexiglas humidity-collection chamber (61 × 30.5 × 30.5 cm) was placed over the humidifier's exhaust (see Fig. 1). The RH of the intake air was monitored by a hygro-thermograph in a clear Plexiglas chamber (62.3 × 31.8 × 32.4 cm), and humidity was added or not depending upon the prevailing room air RH (i.e., $\leq$40% ambient RH led to use of the system). Humidifier fan speed was regulated manually with a rheostat (Staco Energy Products, Dayton, Ohio).

Cooling System

As with many older research facilities, T of the room air in our laboratories was poorly regulated (22 ± 6°C). Control of ambient room T during extreme hot and cold weather was augmented with 2 supplemental 15,000-BTu window-mounted air conditioners (White-Westinghouse Appliance Co., Pittsburgh, Pa.) and 2 Chromalox electric space heaters (Emerson Electric Co., St. Louis, Mo.), respectively. The combustion of RP/BR caused considerable heat buildup in the exposure chamber. To counteract this heat buildup, the postcombustion intake line was modified to consist of a 2.0-m length of 5.6-cm (ID) flexible stainless steel pipe and a U-shaped segment of 5.6-cm (ID) rigid stainless steel pipe 2.5 m high (see Fig. 1). Stainless steel was selected to prevent deterioration from the corrosive properties of the RP/BR aerosol. The base of the U-shaped column was composed of a stainless connector with a 5.6-cm (ID) valve and faucet to permit drainage of condensates. Each 2.5-m-long leg of the U was surrounded by 10.2-cm diameter (ID) rigid PVC pipe. These were sealed at the tops and bottoms with rubber pipe reducers and compression clamps on both the stainless steel intake pipes and the surrounding PVC pipes, forming a sealed water compartment. Each column was plumbed at the top and bottom using 0.8-cm (ID) polyethylene (PE) laboratory tubing that connected to the reservoir of a laboratory waterbath (Messergate-Werk Lauda, Federal Republic of Germany); the PE hose divided (plastic T-joint) about 30 cm from the 2 columns to provide efficient water circulation. The water entered the base and exited the top of each column then joined via another T-joint for return to the bath's reservoir (see Fig. 1). All water-supply tubing and the PVC columns were covered with 2.54-cm-thick rubber insulation to enhance cooling. Circulation of 1°C water through the cooling system is a decision of the operator based upon ambient room T, expected heat buildup, and number of animals in the chamber.

EFFICACY OF THE SYSTEMS

Table 1 presents descriptive statistics (mean ± SDs and ranges) for three sets of RH and T data collected during preliminary tests of our unit; these statistics demonstrate the improved control of RH and T afforded by the humidifying and cooling modifications.

Elevation of Within-Chamber Relative Humidity

The top section of Table 1 presents statistics of representative ambient RH values obtained for the inhalation chamber room versus the within-chamber environment during combustion tests conducted at 500 and 250 l/min air flows and a 250 μm RP/BR-extrusion pump setting. Data refer to RH values collected 1 h after the start of combustion trials; this is typically a time of increased heat buildup (i.e., decreased RH). Room RH was measured with a hygro-thermograph, and within-chamber RH was determined with wet- and dry-bulb thermometers using standard charts corrected for altitude (U.S. Department of Commerce, 1965).

Mean (±SD) room RH values were 15.4 (± 2.5) and 16.3 (±3.5)% whereas within-chamber RH values were 39.3 (±4.3) and 42.3 (±6.4)% for the 500 and 250 l/min air flow conditions, respectively. Thus, use of the humidifying system led to within-chamber RH roughly 2.5 times that of the ambient level.

Reduction of Within-Chamber Temperature

The middle data set in Table 1 shows average chamber T recorded during similar tests conducted before and after installation and use of the cooling system. Temperatures were obtained with a digital thermometer (Van Waters and Rogers, Denver, Colo.) inserted through a sealed port in the sidewall of the chamber.

Mean (±SD) chamber T values of 31.3 (±1.1) and 32.3 (±1.8)°C characterized the trials prior to installation of the cooling system; mean (±SD) readings of 20.7 (±0.5) and 22.1 (±1.3)°C were obtained with the cooling towers in operation. These latter T values represent about a 10°C decrease in heat buildup using the cooling system—T values considered acceptable (nonstressful) for most mammalian and avian species.

Effectiveness of the Humidifying and Cooling Systems

The bottom data set in Table 1 summarizes the within-chamber RH and T readings obtained during an extensive aerosol uniformity study

TABLE 1. Descriptive Statistics for Sets of Representative Data Confirming the Effectiveness of the Humidifying and Cooling Systems

Data set	Test	Air flow (l/min)	Extrusion setting (μm)	Combustion trials (n)	Relative humidity (mean ± SD%; min-max%)	Temperature (mean ± SD°C; min-max°C)
Room vs. chamber RH	Room	500	250	8	15.4 (±2.5); 12–20	
	Chamber	500	250	8	39.3 (±4.3); 30–43	
	Room	250	250	8	16.3 (±3.5); 10–20	
	Chamber	250	250	8	42.3 (±6.4); 32–51	
Pre- vs. postcooling T	Uncooled	500	250	2		31.3 (±1.1); 30.5–32
	Cooled	500	243	8		20.7 (±0.5); 20–21
	Uncooled	250	250	2		32.3 (±1.8); 31–33.5
	Cooled	250	270	8		22.1 (±1.3); 20–24
Routine chamber RH and T	Diverse conditions	500	43, 123, or 243	21	44.4 (±5.9); 30–56	21.2 (±1.1); 19.5–24
		250	125,188, or 270	16	42.5 (±6.3); 32–56	21.7 (±1.2); 20–24

Note. In general, greater combustion (heat) is associated with less air flow and greater extrusion settings (min–max = minimum–maximum).

of the inhalation system (see Sterner et al., 1987). These data reflect combined measurements of within-chamber RH and T during twenty-one 1 h burns of the RP/BR product for 43, 123, or 243 μm extrusion settings with 500 l/min air flow and sixteen 1-h burns at 125, 180, or 270 μm extrusions with 250 l/min air flow. Note that RH averaged 44.4 ($\pm$5.9) and 42.5 ($\pm$6.3)% across these combustion tests, with minimum-maximum RHs of 30–56 and 32–56, respectively. Additionally, the T data reflect the excellent control of heat buildup that the cooling system provided for chamber air—mean T values were 21.2 ($\pm$1.1) and 21.7 ($\pm$1.2)°C for the 500 and 250 l/min air flow conditions with minimum-maximum readings of 19.5–24 and 20–24°C, respectively.

These data confirm the effectiveness of our system to control chamber RH and short-term (1–1.5 h) T for the conduct of animal inhalation studies. Although not presented, extensive data on operation of our system has also shown that long-term (2–3 h) control of chamber T is provided, assuming that ambient chamber-room air is conditioned to 20°C.

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